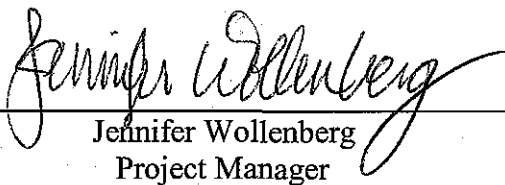



**UPDATED AERIAL PHOTOGRAPH ANALYSIS
TECHNICAL MEMORANDUM
for
BERRY'S CREEK STUDY AREA:
SCOPING ACTIVITIES TASK 2**

Prepared for:
BCSA Cooperating PRP Group

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1.0 INTRODUCTION

In accordance with the Scoping Activities Work Plan (SAWP) for the Berry's Creek Study Area (BCSA), an evaluation of current and historic aerial photographs was conducted to identify human and natural influences that have modified the physical template of the BCSA watershed. The evaluation focused on the identification of landscape alterations that have influenced the channel stability of Berry's Creek and its associated tributaries, and is consistent with the reconnaissance level assessment phase of the U.S. Environmental Protection Agency's (USEPA) funded *Watershed Assessment of River Stability and Sediment Supply* (WARSSS) method (Rosgen, 2006 and references therein; USEPA, 2006), as well as other relevant guidance (USEPA 2008, American Society of Civil Engineers, 1997; McLusky and Elliott, 2004). Specifically, the WARSSS method is a holistic, geomorphology based watershed approach that differentiates natural geologic erosion rates from human influences and quantifies these effects on channel stability. Therefore, factors such as filling of wetlands, development activities, stream channel losses and gains, channel stability, and placement/construction of road crossings throughout the BCSA between the years of 1930 and 2002 were included in the aerial photograph analysis. The results of the aerial photograph analysis will be used to identify features and/or conditions that could influence the chemical and biological template of the BCSA and directly affect the selection of future sampling locations or investigation strategies associated with the RI/FS.

This report summarizes the aerial photograph analysis and highlights particular features and/or changes with oversized figures that facilitate the understanding of the existing condition of the BCSA. Specifically, an overview of the selection of years for aerial analysis and the compilation of relevant considerations is presented in Section 2; the aerial photograph interpretation results as they relate to landscape alteration and channel stability are presented in Section 3; and, Section 4 presents the major findings of the aerial photographs analysis task.

2.0 AERIAL PHOTOGRAPH SELECTION AND COMPILATION

The purpose of the aerial photograph analysis is to evaluate changes to the BCSA watershed that impact waterways and associated wetlands over time. For the purposes of analysis, the selection of aerial photographs and interpretation was divided into two segments of the BCSA.

- Tidal – Analysis of the uncontrolled tidal reach of the BCSA (downstream of tide gates on the Riser Ditches and Peach Island Creek) involved a more detailed aerial photograph interpretation because of the relatively higher incidence of change (i.e., filling wetlands, repeated channelization and natural channel changes) evident in the aerial photographs.
- Non-Tidal (dampened tidal influence) – The dampened tidal and non-tidal reaches above the tide gates on the Riser Ditches and Peach Island Creek were evaluated with fewer aerial photographs because of the large area and the lower incidence of continuous change after the initial construction and development period prior to the 1930 aerial photograph.

In order to ensure a comprehensive analysis, a prioritized list of years for initial aerial photograph analysis was developed based on a review of the available aerial photograph coverages (Table 1) and the storm event history in the BCSA (Table 2). The initial prioritized list included the first available year in which a complete set of aerial photographs was available (1930) and 10-20 year intervals following this period (i.e., years 1951, 1961, and 1971, and 2002). In addition to providing adequate distribution of photographs over time, the occurrence of major storm events likely to have impacted drainage patterns was also considered during the selection of the years of analysis and resulted in the addition of the 1947 (bracket the 1950 Nor'easter) and 1974 (bracket 1972 Tropical Storm Agnes) aerial photographs. As presented in Table 3, aerial photographs from 7 years were selected for initial analysis of the tidal and non-tidal portions of the BCSA.

Following the initial evaluation of aerial photographs and issuance of a Draft Technical Memorandum in December 2007, it was determined in consultation with the USEPA that the analysis would be strengthened by incorporating 3 additional years to fill data gaps and evaluate time periods when extensive modifications to the watershed occurred. Aerial photographs were subsequently obtained for the tidal portions of the BCSA for 1968, 1989, and 1994, resulting in a total of 10 evaluation years (Table 3). Similar to the initial analysis, each of these additional years were reviewed and relevant features including landfill areas/activities, channel constrictions/crossings, and stream losses/gains were quantified and compared. Based on the results of the initial analysis, more than 60% of the wetland loss in the BCSA occurred prior to 1971; therefore, wetland acreages (gains and losses) were not reevaluated as part of the secondary analysis (Section 3.1.1).

Table 1
Aerial Photograph Availability
Berry's Creek Study Area

Year	Resolution	Stereoscopic Available	Electronic Available	Source
1930	NA	No	Yes	NJ Office of Information Technology
1939/40	1"=1667'	Yes	Yes	Aerial Viewpoint
1947	1"=1000'	Yes	Yes	Robinson Aerial Surveys
1951	1"=1667'	Yes	Yes	Aerial Viewpoint
1953	1"=1500'	Yes	Yes	National Aerial Resources
1953	1"=1667'	Yes	Yes	National Aerial Resources
1954	1"=1500'	Yes	Yes	National Aerial Resources
1957	1"=1600'	Yes	Yes	Robinson Aerial Surveys
1959	1"=1500'	Yes	Yes	Robinson Aerial Surveys
1960	1"=3083'	Yes	Yes	National Aerial Resources
1961/62	1"=1500'	Yes	Yes	Aerial Viewpoint
1962	1"=1000'	Yes	Yes	National Aerial Resources
1963	1"=1200'	Yes	Yes	Robinson Aerial Surveys
1966	1"=1500'	Yes	Yes	Robinson Aerial Surveys
1966	1"=2003'	Yes	Yes	National Aerial Resources
1968	1"=1200'	Yes	Yes	Robinson Aerial Surveys
1969	1"=1500'	Yes	Yes	Aerial Viewpoint
1970	1"=1200'	Yes	Yes	Robinson Aerial Surveys
1971	NA	Unknown ¹	Yes	LECG, LLC
1974	1"=1500'	Yes	Yes	Aerial Viewpoint
1976	1"=6500'	Yes	Yes	National Aerial Resources
1978/79	1"=1000'	No	Unknown ¹	Keystone Aerial Photos
1984	1"=6667'	Yes	Yes	National Aerial Resources
1985	1"=4833'	Yes	Yes	National Aerial Resources
1988	1"=800'	Yes	Yes	Robinson Aerial Surveys
1989	1"=2000'	Yes	Yes	Robinson Aerial Surveys
1991	1"=1600'	No	Unknown ¹	Keystone Aerial Photos
1991	1"=4833'	Yes	Yes	National Aerial Resources
1994	1"=4833'	Yes	Yes	National Aerial Resources
1994	1"=1700'	No	Yes	Keystone Aerial Photos
1995	1"=4833'	Yes	Yes	National Aerial Resources
1995	1"=5283'	Yes	Yes	National Aerial Resources
1995	NA	No	Yes	NJ Office of Information Technology ²
1997	1"=2000'	Yes	Yes	Robinson Aerial Surveys
2002	NA	No	Yes	NJ Office of Information Technology
2003	1"=1700'	No	Unknown ¹	Keystone Aerial Photos

Notes:

1. Source did not indicate if format is available.
2. High resolution aerial photographs for the years 1995 and 2002 are available from the NJ Office of Information Technology website free of charge.

Table 2
Storm/Flood Events Berry's Creek Study Area

Year	Event
9/10/1938	New England Hurricane
Sep-44	Great Hurricane of September
1950	Nor'easter
Aug-54	Hurricane Carol
Aug-55	Hurricane Connie & Diane
Sep-60	Hurricane Donna
Jun-72	Tropical Storm Agnes
Sep-85	Hurricane Gloria
1992	Nor'easter
1/9/1993	Nor'easter hit the Atlantic Coast, Coastal Flood
3/4/1993	Nor'easter hit the Atlantic Coast, Coastal Flood
3/13/1993	Nor'easter hit the Atlantic Coast, Coastal/tidal Flood
3/28/1993	Flood
11/28/1993	Flood/Flash Flood
1/28/1994	Urban Flood - Northern NJ
3/3/1994	Coastal Flooding
3/9/1994	Flash Flood
6/11/1995	Flash Flood
7/8/1994	Flood/Flash Flood
Aug-95	Hurricane Felix
10/21/1995	Urban Flood - Bergen
10/28/1995	Urban Flood - Bergen
Jul-96	Hurricane Bertha 7/13/1996 - Flooding, Allendale, Mahwah, Hohokus, Oakland, Lodi
Sep-96	Hurricane Edouard
1/23/1998	Urban/Small Stream Flood
2/24/1998	Coastal Flooding
5/24/1999	Urban/Small Stream Flood
1/3/1999	Flood
Aug-99	Hurricane Irene
8/26/1999	Flood
9/16/1999	Flood
Sep-99	Hurricane Floyd
12/17/2000	Flood
8/14/2001	Urban/Small Stream Flood
7/19/2002	Urban/Small Stream Flood
Oct-05	Nor'easter, 10/8/2005, 10/12/2005 Flooding

Source: Based on information obtained from the National Oceanographic and Atmospheric Administration (NOAA) and the New York City Office of Emergency Management.

Table 3
Selected Aerial Photograph Information for the Berry's Creek Study Area

Year	Month Taken	Source	Number of Aerials Evaluated	Portion of BCSA Evaluated	Analysis Phase	General Notes
1930/33	Various months 1930 to 1933	NJ Office of Information Technology	1	All tidal and non-tidal	Initial	Black and white composite image Second generation product - Accuracy is +/- 50' to 100' Image Quality – moderate, somewhat blurred, dark sections
1947	April	Robinson Aerial Surveys	12	Tidal only	Initial	Black and white Lack complete coverage of the study area Image Quality – excellent, crisp and clear
1951	April	Aerial Viewpoint	6	All tidal and non-tidal	Initial	Black and white Image Quality – moderate, somewhat blurred
1961/62	April	Aerial Viewpoint	5	Tidal only	Initial	Black and white Image Quality – moderate, somewhat blurred
1968	August	Robinson Aerial Surveys	6	Tidal only	Expanded	Black and white Image Quality – excellent, crisp and clear
1971	May	LECG, LLC	1	All tidal and non-tidal	Initial	Color Image Quality – poor, blurred image
1974	March/April	Aerial Viewpoint	5	Tidal only	Initial	Black and white Image Quality – poor, blurred image
1989	September	Robinson Aerial Surveys	2	Tidal only	Expanded	Black and white Image Quality – very good, crisp, somewhat dark in sections
1994/95	April	Keystone Aerial Surveys	4	Tidal only	Expanded	Black and white Image Quality – excellent, crisp and clear
2002	February to April	NJ Office of Information Technology	26	All tidal and non-tidal	Initial	Color Image Quality – excellent, crisp and clear

Two years (1930 and 2002) of aerial photographs were provided to ELM in a georeferenced format (NJ State Plane, NAD 83). Using the 2002 aerial photographs as a base map, the other aeriels were georeferenced using 2-3 points per aerial and tiled to create a mosaic of the watershed and allow a meaningful comparative analysis. Aerial photographs for each year were then plotted at a scale of 1" = 300' for visual analysis of both the tidal and non-tidal portions of the Berry's Creek watershed. Each plotted aerial was reviewed and relevant features including, but not limited to, wetlands, landfill areas/activities, channel constrictions/crossings, stream losses/gains were identified and clearly marked on the aeriels. These data were then digitized using AutoCAD and scaled images were generated for each year to facilitate year to year comparisons of changes, and to create a format that provides for an overview of the entire BCSA for each year.

3.0 AERIAL PHOTOGRAPH INTERPRETATION

As previously stated, the purpose of the historic aerial photograph analysis is to identify and document the physical changes that have occurred in the waterways and wetlands of the BCSA's 7,690 acre watershed. Characterization of these changes will facilitate a better understanding of the ecological response to physical stressors as well as shifts in the morphology of the waterways over time. Specifically, an assessment of the landscape alterations including, but not limited to, wetland losses associated with human activity and development, the progression of fill/development activities throughout the watershed, the loss and gain of channels through time, and the disruption/constriction of natural stream flows was conducted. In addition, channel geomorphology (stream widths, lengths, etc.) was measured and responses to storm events were identified to assess channel stability in the BCSA over the 72-year period between 1930 and 2002.

3.1. Landscape Alteration

As presented in the SAWP, the wetlands in the Meadowlands have been subject to filling and manipulation for over 150 years. From the 1600s into the late 1800s the white cedar swamps were cut to build ships and roads; the cattails and large reed grasses were harvested for thatch and other items; and, the meadow cord grass was mowed for hay (New Jersey Meadowlands

Commission, 2004) leaving a disturbed wetland landscape that was readily colonized and dominated by *Phragmites* (Marshall, 2004). Furthermore, a progression of diversions of flow for water supply lead to the construction of the Oradell Dam on the Hackensack River in 1921, drastically altering the salinity profile and sediment supply within the BCSA and the greater Hackensack Meadowlands, and contributing to changes in the vegetation community. In addition, wetland/open water areas throughout the BCSA have historically been 1) ditched to control mosquitoes and manage vegetation; 2) drained to improve agriculture and facilitate development; and 3) filled to control flooding (levees) and allow development, including the construction of transportation routes/roads (Malcolm Pirnie, 2005).

Following implementation of the reorganized and expanded 1972 version of the Federal Water Pollution Control Act (Act), popularly known as the Clean Water Act, activities in the wetlands and water resources within the BCSA were regulated. Specifically, in order to protect wildlife the Act requires permits to dispose of dredged and fill materials into navigable waters. Another provision of the Act that affected the course of development in the BCSA includes the implementation of state water quality standards for eliminating or reducing the pollution of interstate waters/tributaries and improving the condition of surface and underground waters. In addition to the Clean Water Act, the State of New Jersey adopted the Freshwater Wetlands Protection Act (July 1, 1987) that gave the NJDEP authority over Section 404 of the Clean Water Act and authorized the NJDEP to regulate all freshwater wetlands. However, areas under the jurisdiction of the New Jersey Meadowlands Commission (formerly known as the Hackensack Meadowlands Development Commission) are exempt from the jurisdiction of the Freshwater Wetlands Protection Act and are regulated by the U. S. Army Corps of Engineers through the Clean Water Act.

The following sections present the results of the aerial photograph analysis related to the loss of wetland and open water areas (Section 3.1.1), the loss/gain of stream channels (Section 3.1.2), and the increase of channel crossing/constrictions (Section 3.1.3) in the BCSA over time.

3.1.1. Wetland & Open Water Areas

In order to document changes to the acreage of wetland and open water areas between 1930 and 2002, the wetland boundary was demarcated on the 1"=300' aerial photographs for the years of

1930, 1951, 1971, and 2002 (Figure 1). The wetland boundaries for each year were estimated based on the absence of observed fill activities, disturbed/cleared vegetation, and altered hydrology. However, due to the quality of some of the aerial images and the overall limited topographic relief in the Meadowlands it is difficult to ascertain in some areas, particularly in the upper and outer reaches of the watershed (i.e., headwater areas), if the area is a vegetated upland or wetland. In addition, areas in which there was evidence that the area had been cleared and plowed for agricultural use were not identified as wetland areas; however, areas that were cleared but showed no evidence of having been plowed or developed were identified as wetlands if there was evidence of hydrology (i.e., ditches, channels, and surface inundation).

Recognizing that different segments of the BCSA may respond differently to hydraulic stress, the tidal portion of the BCSA was divided into three segments/reaches: Riser Ditch tide gates south to Paterson Plank Road was identified as the upper tidal segment, Paterson Plank Road south to Route 3 was identified as the middle tidal segment, and Route 3 south to the Hackensack River was identified as the lower tidal segment. Each segment included a portion of the main channel of Berry's Creek as well as several man-made and natural tributaries, and the lower segment included the Berry Creek Canal. Following the identification of wetland/open water areas in the four primary segments of the BCSA watershed, the data was digitized to allow a comparison of change in the approximate wetland/open water acreage through time (Table 4). Despite some uncertainties associated with the quality of the aerials and the identification of wetlands in disturbed areas, the reduction of wetland/open water acreages over time is readily apparent and can be reasonably quantified.

In addition to the aerial photograph analysis, an estimate of wetland and open water acreage was obtained from a copy of an 1896 map prepared by the U.S. Geological Survey of New Jersey (Figure 2) that illustrates the historic wetland areas of the BCSA. Similarly, a review of the New Jersey Department of Environmental Protection's (NJDEP) wetland data available on their iMap website was conducted to compare the acreage of wetland areas obtained from their website (1,523 acres) with the acreage obtained via interpretation of the 2002 aerial photograph (1,600 acres). The small difference in the acreages (77 acres) is likely attributed to the fact that the acreage obtained via the aerial photograph analysis includes both wetland and open water areas and the NJDEP acreage only includes wetland areas.

Table 4: Comparison of Wetland/Open Water Acreages between Years of Analysis in the Berry's Creek Study Area.

BCSA Segment	Year of Analysis				
	1896*	1930	1951	1971	2002
Non-Tidal	1,327	801	766	650	375
Upper Tidal	651	720	674	247	178
Middle Tidal	1,241	1,284	1,178	598	356
Lower Tidal	1,146	1,400	1,361	822	691
Total Wetland/Open Water Acreage	4,365	4,205	3,979	2,317	1,600

* The wetland/open water acreages per segment are approximate due to the scale and accuracy of the source map.

Directly related to the loss of wetland/open water area over time is the long history of filling and developing the BCSA wetland/open water areas for agricultural, commercial/industrial, and residential use. As shown in Table 5, an increase in filled/developed areas is another means for assessing impacts to wetland/open water areas over time. Each additional acre filled resulted in the reduction of the tidal prism under some tidal ranges – a factor taken into account in the water budget analysis and conceptual site models.

Table 5: Comparison of Filled/Developed Acreage Increases between Years of Analysis in the Berry's Creek Study Area.

Period of Analysis	1896 to 1930	1930 to 1951	1951 to 1971	1971 to 2002
Increase of Filled/Developed Acreage	160	226	1,662	717

Based on the identification and analysis of changes in the acreage of wetland/open water areas throughout the entire BCSA watershed (7,690 acres in size) in the years of 1896, 1930, 1951, 1971, and 2002, the following observations were made:

- The **1896** Geologic Survey drainage map (Figure 2) of the BCSA shows a relatively undeveloped watershed with a few natural tributaries and some forested wetland areas. The landscape of the 1896 watershed consists of wetland/open water areas (4,365 acres or 57% of the watershed) surrounded by upland areas (3,244 or 43% of the watershed). Although there is a lack of detail on this map regarding the type of development, the map shows that the majority of development is located along the roads and the western portion of the watershed.

- In **1930** the approximate wetland/open water acreage was 4,205. The estimated loss of 160 acres of wetland/open water areas between 1896 and 1930 represents a 2% increase of developed area in the watershed. The loss of wetland/open water area and increase in developed land can be attributed to the addition/construction of a few runways associated with the Teterboro Airport, creation of a golf course north of the airport, and activities associated with a small quarry or brick yard located on the east side of Berry's Creek between Moonachie Avenue and Paterson Plank Road.
- In **1951** the approximate wetland/open water acreage was 3,979; however, the total loss of 226 acres of wetland/open water area over the 21 year period between 1930 and 1951 reflects both a gain and loss. Specifically, the golf course located north of the airport in the non-tidal segment was abandoned prior to 1951 and appears to have reverted to wetland (over 125 acres). However, the addition of 226 acres of developed areas in the BCSA watershed (3% increase) during this period is primarily associated with expansion of the airport in the non-tidal segment; increased quarry/brick yard activities in the upper tidal segment; fill/development activities along Route 17 in the middle tidal segment; construction of Route 3 (middle/lower tidal segments); and, construction of a drive-in theater and the pipeline right-of-way in the lower tidal segment of the BCSA during this period. The greatest loss of wetland/open water area during this period (106 acres) occurred in the middle tidal segment.
- In **1971** the approximate wetland/open water acreage was 2,317, indicating a loss of 1,662 acres of wetland/open water areas throughout the 20 year period between 1951 and 1971. Although there was one notable incident of wetland gain in the non-tidal segment (i.e., an agricultural/developed area located immediately south the airport was abandoned and allowed to revert to wetland; approximately 50 acres), there was a substantial loss of wetland area during this period. The wetland/open water losses that occurred during this period are associated with an increase of development activities and expansion of the airport in the non-tidal segment of the BCSA (i.e., the location of the former golf course); along the eastern edge of the BCSA watershed in both the upper and middle tidal segments; between Paterson Plank Road and Route 3 (middle tidal segment) on the western side of Berry's Creek in the area of Ackerman's Creek; and, along Route 3 (middle/lower tidal segments). In addition, there was a considerable loss of wetland/open

water areas (539 acres) in the lower tidal segment of the BCSA due to filling associated with the solid waste Rutherford Landfill and its access road, creation of the solid waste Old Lyndhurst Landfill, and construction of Interstate 95. Based on the findings of the initial analysis indicating that most of the wetland fill in the BCSA was placed prior to 1972, wetland acreages were not evaluated for 1989 and 1994 during the expanded analysis.

- In **2002** the approximate wetland/open water acreage was 1,600, indicating a loss of 717 acres of wetland/open water areas over the 31 year period between 1971 and 2002. The majority of the wetland/open water loss during this period is associated with a 9% increase of developed areas in the BCSA watershed including expansion of the airport and commercial/industrial areas between Interstate 80 and US Highway 46 (275 acres filled/developed in the non-tidal segment), construction of the Meadowlands Sports Complex (242 acres filled/developed in the middle tidal segment), and expansion of the solid waste landfill areas and commercial/industrial development (131 acres of fill/development) in the lower tidal segment of the BCSA. Other wetland/open water losses during this period can be attributed to the filling/development activities adjacent to Eight Day Swamp and Peach Island Creek (69 acres) in the upper tidal segment.

Over the past 106 years (1896 to 2002) there has been a loss of approximately 2,696 acres of wetland/open water areas in the BCSA watershed; in other words, there were 2.6 times more wetland/open water areas present in 1896 than there were in 2002 and the BCSA watershed was 78% developed in 2002 compared to only 44% in 1896. The majority of the losses occurred prior to implementation of the expanded Clean Water Act of 1972 and the regulation of filling/dredging activities in wetland and open water areas. Specifically, between the years of 1896 and 1951 there was a total loss of wetland/open water areas of approximately 361 acres (13% of the total wetland/open water loss and 5% of the total BCSA watershed area); between 1951 and 1971 there was a loss of 1,675 acres (62% of the total wetland/open water loss and 22% of the total BCSA watershed area); and, between 1971 and 2002 there was a loss of 717 acres (25% of the total wetland/open water loss and 9% of the total BCSA watershed area). The average annual loss of wetland/open water areas during the 20-year period between 1951 and 1971 was 84 acres, compared to the average annual loss of 21 acres of wetland/open water areas during the 31-year period between 1971 and 2002. Based on this comparison, it appears that the

rate of development in wetland/open water areas in the BCSA has been substantially reduced over the past 30 years.

These patterns of wetland/open water loss are consistent with the trends observed by Tiner (2002), and in fact the rates of wetland/open water loss in the BCSA were less than or equal to the loss rates measured for the entire New Jersey Meadowlands Commission district for similar periods of time (1953/54-1995). Comparison of the total area of wetlands/open water depicted on the 1896 topographic map and the 2002 aerials indicate that approximately 37% of the 19th century wetlands remain in the BCSA. This proportion indicates that wetlands/open water losses in the BCSA are notably lower than losses in the Hackensack Meadowlands as a whole, where development and other filling activities have left only 28% of 19th century wetlands intact (Tiner, 2002).

3.1.2. Channel Losses and Gains

As part of the landscape alterations associated with the BCSA, there is a long history of altering and creating channels throughout the watershed to control mosquitoes, improve drainage in agriculture fields, facilitate development, and control flooding. Therefore, in order to document this history and evaluate the changes in the number and location of channels over the past 70 years in the tidal portions of the BCSA a comparison of the aerial photographs was conducted. Specifically, aerial photographs for each year were reviewed to identify 1) channels that were not present on the preceding aerial (i.e., gained), and 2) channels that were not present on the following aerial (i.e., lost) (Figures 3A/3B and Table 6). Self-formed channels were distinguished from those that were constructed based on an analysis of the channel's construction history and/or natural geomorphology indicated primarily by sinuosity. Ponds and other non-channelized areas of open water were not included in this assessment.

Based on the identification and analysis of channel losses and gains throughout the tidal portions of the BCSA between the years of 1930 and 2002 (Table 6), the following observations were made:

- The **1896** drainage map (Figure 2) of the BCSA shows a number of man-made drainage ditches as well as several natural, meandering tributaries of Berry's Creek. In addition, the **1930** aerial photograph continues to show an extensive, more developed, network of

man-made drainage ditches (i.e., a ditch that parallels the western side of the lower tidal segment of Berry's Creek). However, the channel gains and losses associated with water management activities (e.g., modifications in surface hydrology) implemented prior to 1930 were not quantified as part of this assessment.

Table 6: Comparison of Channel Losses and Gains Between Years of Analysis in the Berry's Creek Study Area

Period of Analysis	Channel Gain (ft)	Channel Loss (ft)	Net Gain/Loss (ft)
1930 to 1947	37,248	3,565	33,683
1947 to 1951	1,253	955	298
1951 to 1961	20,514	24,964	-4,450
1961 to 1968	26,179	76,540	-50,361
1968 to 1971	7,508	39,121	-31,613
1971 to 1989	8,470	53,148	-44,678
1989 to 1994	1,558	0	1,558
1994 to 2002	1,899	340	1,559
Totals	104,630	198,633	-94,003

- The channel gain/loss activity in the period between **1930 and 1947** resulted in an overall gain (i.e., 6.4 miles) of man-made, linear channels associated with construction of Route 3, a levee/channel system located along the eastern side of Berry's Creek between Paterson Plank Road and Route 3, and a channel parallel to the Canal similar to the drainage feature/ditch that parallels the lower tidal segment of Berry's Creek. The channel losses in this period were associated with some agricultural activity (i.e., clearing and expansion of existing fields) in the upper tidal segment and the loss of a few drainage ditches where Route 3 was constructed across the watershed.
- There was little channel gain/loss activity in the period between **1947 and 1951**. Although there was an overall increase of 298 feet in the linear distance of channels in this period, the amount of linear feet gained and lost during this period were similar. All the channel gains/losses during this 4-year period occurred in the upper tidal segment of the BCSA and are minor in comparison to the changes experienced during the other time periods evaluated as part of the aerial photographs analysis.
- The linear distance of channel gain and loss between years **1951 and 1961** were similar but there was an overall loss of 4,450 linear feet of channel in the tidal portion of the

BCSA during this period. The majority of the channel losses during this period were associated with development/fill activities concentrated along Route 3 and Paterson Plank Road, as well as expansion activities around the quarry/brick yard. There was one natural, meandering tributary located on the west side of the upper tidal segment of Berry's Creek, below Moonachie Avenue, lost during this period. The gains that occurred in this 10-year period primarily consisted of the construction of linear ditches/channels in the middle tidal segment of the BCSA.

- Development activities within the BCSA between **1961 and 1968** resulted in the most extensive net channel losses measured for all periods evaluated, with a net loss of over 50,361 linear feet (9.5 miles) of channel. Specifically, 26,179 feet (5 miles) were gained and 76,540 feet (14.5 miles) were lost in this 7 year period. Numerous ditches in the lower tidal segment were lost as a result of activities at the Rutherford landfill near the confluence of Berry's Creek and the Hackensack River, as well as road construction at Route 3 and Interstate 95. Construction of commercial and warehousing facilities on the western side of the middle tidal portion of Berry's Creek, across from Walden Swamp, accounts for much of the net channel loss during this period. One notable loss associated with this development was the natural, meandering channel of the original Ackerman's Creek. Other changes during this period include the filling of many of the ditches/channels that drained into Peach Island Creek (upper tidal segment) for development of commercial facilities.
- The period between **1968 and 1971** resulted in the net loss of 31,613 feet (6 miles) of channels and ditches as development encroached towards the center of the tidal portion of the BCSA. Most of the losses during this time period occurred in the upper tidal segment north of Paterson Plank Road, and were the result of expanding commercial development. In addition, some losses in the middle and lower tidal segments were associated with road construction at Route 3 and Interstate 95, as well as Route 3 and Route 17. Small gains throughout the watershed were primarily associated with road construction.
- From **1971 to 1989**, 53,148 linear feet (10 miles) of channel and ditches were lost and approximately 8,470 linear feet (1.6 miles) of channel were created. The majority of the losses were associated with the construction of the Meadowlands Sports Complex in the middle tidal segment of the watershed, between 1972 and 1976. Other losses were the

result of expanding commercial development throughout the watershed. Channel gains in this time period are mainly the result of road construction and re-routing of previously existing ditches during construction of commercial facilities throughout the watershed.

- No channel loss was observed between 1989 and 1994. A total gain of 1,558 linear feet (0.3 miles) of channel was accrued, primarily resulting from the extension of 2 linear ditches in the lower tidal segment of the watershed, to the south of Berry's Creek.
- From 1994 to 2002, only 340 feet of channel were lost, and 1,899 feet were gained, for a total net gain of 1,559 linear feet (0.3 miles). Gains occurred at 2 locations in the middle tidal segment, adjacent to the railroad across from the NJ Sports Complex, and a small extension of a tidal creek in Walden Swamp. Additionally, a small side channel was formed off of the southern side of Peach Island Creek in the upper tidal segment. The causes of these gains are not apparent. Channel loss occurred in only 1 location, in the lower tidal segment, and is due to the filling of a small ditch/tributary to Berry's Creek. The loss appears to be associated with a commercial facility.

Approximately 37.6 miles of channel were lost and 19.8 miles of channel were gained during the 72-year period between 1930 and 2002, resulting in an overall loss of approximately 17.8 channel miles. Similar to the wetland/open water acreage loss experienced in the BCSA watershed, the majority of the channel losses (i.e., 26.6 miles) occurred between 1951 and 1971, prior to the 1972 Clean Water Act amendments. Specifically, the average annual channel loss during the 20-year period between 1951 and 1971 was 7,031 linear feet (1.3 mile) per year, compared to the average annual channel loss of 1,725 linear feet (0.3 mile) per year during the 31-year period between 1971 and 2002. Based on this comparison, it appears that the rate of channel loss/filling in the BCSA has been substantially reduced over the past 30 years.

3.1.3. Channel Crossings

As part of the landscape alteration assessment to identify potential effects of natural or human influences on the physical template of the BCSA, all the road and railroad crossings, tide gates, and channel constrictions (e.g., blocked/filled) on the main channel of Berry's Creek, as well as the Berry's Creek Canal and primary tributaries, were identified on the 2002 aerial photographs

(1"=300'). Following the identification of these features on the 2002 aerial photographs, the aerial photographs (1"=300') for the other 9 years of analysis were reviewed to determine when the feature first appeared and provide a timeframe in which it was originally constructed. It should be noted that aerial photographs evaluated during the expanded analysis (1968, 1989, 1994) only covered the tidal portions of the BCSA, so the time frame for the construction of some crossings in the non-tidal portion are not as well constrained as those in the tidal portion of the watershed.

Based on the analysis of the 42 channel crossings/constrictions identified in the BCSA in the year 2002 (Figure 4), the following observations were made:

- The 1896 map clearly shows the Moonachie Avenue, Paterson Plank Road, and the NJ Transit railroad crossings; however, a detailed analysis of additional data presented on this map is not practical. Therefore, all these crossings and 2 other minor road crossings are identified as occurring pre-1930 and represent 8 of the total 42 crossings (19%).
- In the period between 1930 and 1947, 3 crossings were constructed. Two crossings were associated with construction of Route 3. The third crossing was the West Riser tide gate in the upper tidal segment of the study area. The original East Riser tide gate was also constructed during this time period. An additional 2 crossings were constructed over the West Riser Ditch and one crossing over the East Riser Ditch between 1930 and 1951.
- One crossing was constructed between 1947 and 1951, consisting of a small road located at the southern end of the Teterboro Airport crossing the West Riser Ditch.
- In the period between 1951 and 1961, 2 crossings were constructed in association with the pipeline right-of-way in the lower tidal segment of the BCSA. An additional 2 crossings, one on each of the Riser Ditches north of Route 46, were constructed between 1951 and 1971.
- In the period between 1961 and 1968, 12 crossings were constructed. Five of these are associated with the development/channelization of the East Riser Ditch, and 2 are the result of construction across Peach Island Creek, including the Peach Island Creek tide gate. Development to the west of Berry's Creek, south of Paterson Plank Road, also resulted in 2 new crossings. Construction activities for Interstate 95 resulted in 1

crossing, and landfill activity in the lower tidal segment of the BCSA created 2 new crossings.

- Four crossings were constructed in the period between 1968 and 1971. All of these are associated with the construction of Interstate 95 and the related interchange at Route 3.
- In the period between 1971 and 1974, 3 crossings were constructed: one of these was the construction of the Rutherford tide gate, and the other 2 are associated with development on the west side of Berry's Creek near Route 3. In addition, 2 crossings were constructed in the northern, non-tidal portion of the BCSA between 1971 and 2002. One is adjacent to Teterboro Airport, and the other is associated with Route 17 immediately south of U.S. Highway 46.
- Two crossings were constructed in the period between 1974 and 1989. One of these was the existing East Riser tide gate; however, it should be noted that there was an earlier tide gate on the East Riser Ditch that was constructed between 1930 and 1947 but was subsequently removed – the original tide gate was located further upstream than the existing tide gate. The other crossing is associated with a new development located between Route 3 and Interstate 95 on the west side of Berry's Creek.

As of 2002, there were 42 channel crossings throughout the BCSA. Consistent with the other landscape alteration observations, the majority of the existing crossings (16 out of 42, 38%) were originally constructed between the years 1961 and 1971. The second greatest number of crossings (8 out of 42, 19%) were constructed prior to 1930.

Included in the crossings identified throughout the BCSA are 4 tide gates that regulate the extent of tidal influence in the watershed. The Rutherford tide gate is located in the lower tidal segment, and the Peach Island Creek, East Riser, and West Riser tide gates are located in the upper tidal segment. The construction of the tide gates has greatly reduced the tidal prism upstream of these locations, but due to improper functioning of the tide gates some tidal influence still extends upstream, to approximately Moonachie Avenue. Additionally, the tidal prism extended further upstream on the East Riser Ditch until that tide gate was relocated relatively recently. The tide gate on the East Riser Ditch was originally constructed between 1930 and 1947, but was subsequently moved downstream to its present location between 1974 and 1989 when Grand Avenue was realigned.

3.2. Channel Stability

Similar to the history of landscape alteration in the BCSA, the past and current channel stability of Berry's Creek and its tributaries was assessed to determine if human and natural influences had impacted the morphology or stability of channels in the BCSA. Evaluations were based on the WARSS reconnaissance level assessments procedure (Rosgen, 2006; USEPA, 2006), which provides a framework for the assessment of sediment and river stability, as well as other relevant guidance (USEPA 2008, ASCE, 1997; McLusky and Elliott, 2004). Specifically, this assessment provides a landscape level appraisal of hydrologic and channel processes that may influence sediment sources and distribution in the BCSA. The aerial photograph analysis included an evaluation and sequential comparison of changes in channel geomorphology (Section 3.2.1), channel widths (Section 3.2.2), and geometry of natural tributaries (Section 3.2.3). In addition, the analysis attempted to evaluate movement of the channel thalweg within the banks but was unable to qualitatively or quantitatively assess this condition due to the scale of the aerial photographs, image quality/resolution (i.e., clarity, shadows, sun glare, clouds and smoke, etc.), and the lack of data regarding tide heights (time of day) when the photographs were taken. Detailed current data regarding channel widths and morphology, including the position of the thalweg, may be found in the Bathymetry, Sidescan Sonar, and Geophysical Survey report for the BCSA (Earthworks, Inc., 2008).

As previously described, the tidal portion of the BCSA was divided into three segments/reaches which were evaluated separately: the upper tidal segment (Figures 5A/B), the middle tidal segment (Figures 6A/B), and the lower tidal segment (Figures 7A/B). Each segment included a portion of the main channel of Berry's Creek as well as several man-made and natural tributaries, and the lower segment included the Berry Creek Canal. In order to assess channel stability over the past 72 years (1930 to 2002), a number of cross-sections were identified along the main channel in each segment. In addition, a natural tidal stream identified on the 1896 map was selected for measurement in each segment (refer to Section 3.2.3). Measurements of the main channel and the Canal focused on the channel widths at select points over time; however, assessment of the natural tributaries included measurements of the stream length, belt width (i.e., the lateral distance between the outside edges of two meanders that occur on opposite sides), and meander wave-length (i.e., the longitudinal distance between two sequential meanders), as well

as channel width at several points (Rosgen, 1996). All the channel measurements were tabulated and are graphically represented on the figures for each segment.

3.2.1. Channel Geomorphology

In conjunction with the channel and ditch losses and gains (Section 3.1.3), the main channel and tributaries of Berry's Creek have adapted naturally in response to the altered hydrologic patterns and sediment input throughout the watershed. The intent of this section is to identify the stream's natural (i.e., oxbows, meanders, etc.) and/or man-made (i.e., channelization, dredging/widening, etc.) geomorphological adaptations over time.

Upper Tidal Segment of the BCSA

This segment consists of Berry's Creek between the Riser Ditch tide gates and Paterson Plank Road, as well as the associated wetlands and tributaries in this reach. Based on the identification and analysis of changes in channel geomorphology throughout the upper tidal segment of the BCSA between the years of 1930 and 2002, the following observations can be made (Figures 5A/B).

- The East Riser Ditch was a natural meandering tributary in 1930 and was channelized above the tide gate that was constructed between 1930 and 1947. The tide gate was later moved further downstream (1974-1989) and a longer length of the upstream channel was channelized (refer to Figure 4 for tide gate locations). During the same time period in which the new tide gate was installed, the confluence of the ditch and main channel changed in size and shape, likely as a result of placement of fill material along the north side of the confluence for construction of a commercial building.
- Man-made ditches into the wetland areas were stable and were not observed to move or change significantly after their construction.
- Two natural meanders located in the stream channel immediately above the West Riser tide gate became small islands between 1930 and 1947 when the West Riser Ditch was channelized and straightened in that area. The northernmost of the meanders and islands was lost between 1947 and 1951. The remaining meander and associated island were later filled or lost between 1951 and 1968. Their presence or absence could not be confirmed

on the 1961 aerial photo due to smoke obscuring the image. Construction of commercial facilities and placement of fill material occurred in this area simultaneous to the channel alterations and may have been the cause of these changes.

- A substantial change occurred in the alignment and width of the main channel located immediately below the West Riser tide gate between the years of 1994 and 2002. The cause of the loss of a small island and a considerable amount of a channel bend; the merging/confluence of an old oxbow with the new channel alignment and the creation of an island; and, the widening of the main channel observed in the 2002 aerial is unclear based on the aerial analysis.
- Limited changes in the channel geomorphology of Peach Island Creek occurred between the years of 1961 and 2002. No major changes in alignment occurred before 1961 nor were there any oxbows or islands formed or lost. The channel width is reduced for an approximately 400 foot length where a road was constructed across the channel (approximately 2,000 feet upstream of the confluence with Berry's Creek) between 1961 and 1968. The tide gate was constructed in this same (constricted) area between 1971 and 1974. The main channel of Peach Island Creek did not change significantly in the period between 1974 and 2002. Other changes associated with the Peach Island Creek area are associated with the loss of channels/ditches over time due to increasing development in the surrounding area (Figures 3A/B).

The overall observation and conclusion is that changes in the geomorphology of the upper tidal segment of Berry's Creek during the period of evaluation were primarily the result of human activity.

Middle Tidal Segment of the BCSA

The middle tidal segment consists of Berry's Creek and associated wetlands and tributaries between Paterson Plank Road and Route 3. Based on the identification and analysis of changes in channel geomorphology throughout the middle tidal segment of the BCSA between the years of 1930 and 2002, the following observations can be made (Figures 6A/B).

- The main channel of Berry's Creek located between Paterson Plank Road and Route 3 has not changed configuration from 1930 to 2002, nor have any islands or oxbows formed along this segment of the creek.
- Man-made ditches into the wetland areas were stable and did not move or change significantly after their construction.
- As presented in Section 3.1.3, a number of the natural and man-made channels/ditches in this area were lost over time due to filling of wetland and open water areas, especially between 1961 and 1971.
- Some isolated areas of open water were created between 1961 and 1968 at the mouth of Ackerman's Creek and in the adjacent wetlands when the majority of the natural, meandering tributary channel was filled and a small portion of the upper reach of the tributary was left undisturbed resulting in the formation of a few isolated oxbow-like features and open water/emergent wetlands.
- The confluence of a natural tributary, located along the northern boundary of Walden Swamp, with the main channel of Berry's Creek has changed over time. Specifically, a small peninsula located at the mouth of the tributary was gradually reduced in width between 1951 and 1974 and was lost between 1974 and 1989, resulting in a wider mouth of the tributary. The cause of the change is not apparent.
- Construction of the Meadowlands Sports Complex in this area between 1974 and 1989 resulted in the loss of numerous channels and ditches (Figure 3B), as well as the addition of a stormwater management system that discharges into Berry's Creek following the collection and treatment of surface water runoff.

The overall observation and conclusion is that the majority of geomorphological changes observed in the middle tidal segment of Berry's Creek during the period of evaluation were a direct result of human activity.

Lower Tidal Segment of the BCSA

This segment of the BCSA consists of Berry's Creek and Canal from Route 3 to the confluence with the Hackensack River, as well as all associated wetlands and tributaries in this reach. Based on the identification and analysis of changes in channel geomorphology between the years of

1930 and 2002 throughout the lower tidal segment of the BCSA, the following observations can be made (Figures 7A/B).

- The general configuration of the channels in this segment of the BCSA, including the main channel of Berry's Creek and the Canal as well as Fish Creek, has not changed substantially over time. The channel alignment and meanders remain the same, and no oxbows or islands have been formed or lost.
- Man-made ditches into the wetland areas were stable and did not move or change significantly after their construction.
- A number of the natural and man-made channels and ditches in this segment of the BCSA have been lost over time, especially between 1961 and 1971 during construction of Interstate 95 and the Rutherford landfill (Figure 3B).
- The geomorphology of the main channel around the confluence of Berry's Creek and the Canal has changed over time in response to the construction of Route 3 (1930-1947), the Rutherford Landfill road crossing west of the railroad (1961-1968), and the Rutherford tide gate (1971-1974).

The overall observation and conclusion is that the geomorphology of the BCSA's lower tidal segment has remained largely unchanged during the period of evaluation, and that the few observed changes in the geomorphology of this segment are the result of human activities.

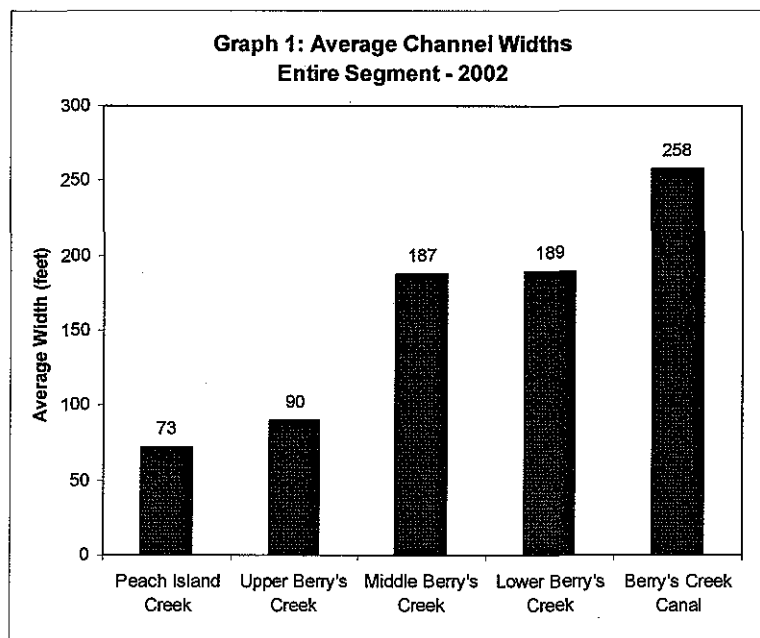
Summary

Berry's Creek and its tributaries have experienced few physical changes over the 72-year period between 1930 and 2002, suggesting a system that is generally stable despite anthropogenic disturbances. The changes that did occur are primarily the result of man-made influences or modifications such as the installation of a tide gate (i.e., West Riser Ditch), the formation of an oxbow-like feature following the filling of other portions of the channel (i.e., remnants of Ackerman's Creek), and the reduction in width due to numerous road crossings (i.e., confluence of Berry's Creek and the Canal). The only significant change that cannot be directly attributed to human activities is the channel reconfiguration of Berry's Creek immediately downstream of the West Riser tide gate between 1989 and 1994.

3.2.2. Channel Widths

As previously stated, a number of cross-sections were identified along the main channel of each segment of the tidal portion of the BCSA in order to assess channel stability over the 72-year period from 1930 to 2002. Channel width measurements were obtained at select points along the main channel of Berry's Creek and Berry's Creek Canal for each year of analysis (Figures 5A/B through 7A/B).

In addition to assessing channel stability, the 2002 channel width measurements were used to evaluate the natural form of the creek and identify any upstream to downstream patterns between the different segments of Berry's Creek (i.e., upper, middle, and lower tidal) as well as the Berry's Creek Canal and Peach Island Creek. Specifically, the average width of each segment was calculated by adding all of the channel widths within that particular segment and dividing by the total number of channel width measurements for that segment. The only exception to this method of calculation was the elimination of the width measurement at cross-section location A in the lower tidal segment of Berry's Creek (Figures 7A/B), due to the large amount of human disturbance that has resulted in a substantially reduced channel width at this location. As would be predicted, the average widths increased in size moving from upstream to downstream within each segment of Berry's Creek and the Canal (Graph 1). Additionally, the average width of Peach Island Creek is smaller than the main channel of the upper tidal segment of Berry's Creek into which it drains, and is indicative of a large tributary.



Despite the expected pattern described above and seen in Graph 1, in 2002 the average channel width in the lower tidal segment of Berry's Creek (189 feet) was almost the same as the average width of the middle tidal segment (187 feet wide). This probably is not characteristic of what the natural channel morphology was prior to extensive development of the BCSA, as undisturbed systems typically widen from headwaters to mouth. The unusually narrow channel in the lower segment is attributed to the creation of the Berry's Creek Canal over 100 years ago and the resultant disruption of the flow pattern and diversion of the lower Berry's Creek flow. The nearly equal average width of the middle and lower Berry's Creek segments suggests that human-enhanced filling or natural sedimentation has taken place in the lower channel segment since the creation of the Berry's Creek Canal.

The channel width cross-section locations for each tidal segment of the BCSA are identified on Figures 5A/B through 7A/B, and the individual measurements at each location for all 7 years of analysis are graphically represented on the figures. In addition, the following presents the results of the channel width analysis for each segment.

Upper Tidal Segment of the BCSA

Based on the channel width measurements obtained at fixed locations for each of the selected years of analysis (refer to Graph 2 presented on Figures 5A/B), the following observations were made for the upper tidal segment of the BCSA.

- Channel widths were measured at 7 locations in the upper tidal segment of the BCSA: 5 were located along the main channel of Berry's Creek and 2 were located along the lower reach of Peach Island Creek. All the channel width measurements, except for location E along the main channel, exhibit little variation over the 72-year period of analysis and are indicative of a stable stream.
- Width measurements obtained at location E, which is situated approximately 450 feet upstream of the Paterson Plank Road crossing and 400 feet downstream of the confluence

with Peach Island Creek, were relatively stable between 1930 and 1951 at which point there was a decrease in channel width (i.e., 60 foot reduction) between 1951 and 1961. Based on a review of the 1961 aerial photograph, it appears that the channel was reduced in width at this location to accommodate some new development along Paterson Plank Road. Following this reduction in channel width between 1951 and 1961, the channel width measurements once again stabilize and are consistent with the pattern observed at the other measurement locations between 1961 and 2002. Channel widths upstream and downstream of location E remained stable (+/- 5 feet) before and after the constriction was observed.

- The channel width of Berry's Creek above its confluence with Peach Island Creek (locations A through D) ranged from 73 to 103 feet for all years, with an average width of 73 feet. The range of channel widths for Peach Island Creek was 55 to 86 feet for all years, with an average width of 66 feet. At the measurement location below the confluence of Berry's Creek and Peach Island Creek (i.e., location E), the average channel width for all years is 128 feet, with a range from 100 to 175 feet.

The overall observation and conclusion is that the channel widths of the upper tidal segment of the BCSA have not changed significantly between 1930 and 2002.

Middle Tidal Segment of the BCSA

Based on the channel width measurements obtained at fixed locations for each of the selected years of analysis (refer to Graph 6 presented on Figures 6A/B), the following observations were made for the middle tidal segment of the BCSA.

- Channel widths were measured at 7 locations in the middle tidal segment of the BCSA. The channel width measurements generally exhibit little variation over the 72-year period of analysis and are indicative of a stable stream.
- Channel width measurements immediately below the Paterson Plank Road crossing, at location A, decreased from an average of 143 feet (1930-1974) to an average width of 121 feet (1989-2002). The cause of this decrease is not readily apparent, but is potentially

due to the construction of the Sports Complex during this time period (1974-1989) and related road construction to connect the Sports Complex access road to Paterson Plank Road adjacent to the creek.

- Based on the average width at each measurement location, the average channel width of Berry's Creek varies between 136 (location A) and 220 feet (location G). At the measurement location below the confluence of Berry's Creek and Ackerman's Creek (i.e., location D), the average channel width is 176 feet.
- The channel widths measured below the confluence of Berry's Creek and Ackerman's Creek (i.e., locations D, E, F, and G) experienced a slight increase in channel width following the loss of the natural channel of Ackerman's Creek between 1961 and 1968 but widths were stable between 1968 and 2002. The range of the channel width increases by 1968 at the four locations below the confluence (2 to 27 feet) may reflect measurement variations associated with the lower quality/resolution of the 1961 aerial photographs.
- Channel width measurements at location G, approximately 500 feet upstream of the Route 3 crossing, showed the greatest variability and ranged between +8 and -19 feet from the average channel width of 220 feet at this location.

The overall observation and conclusion is that the channel widths of the middle tidal segment of the BCSA remained relatively stable during the period of evaluation (1930 to 2002) and only varied in response to human modifications and influences in the watershed.

Lower Tidal Segment of the BCSA

Based on the channel width measurements obtained at fixed locations for each of the selected years of analysis (refer to Graphs 10 and 11 presented on Figures 7A/B), the following observations were made for the lower tidal segment of the BCSA, including both the main channel of Berry's Creek (Graph 11) and the Berry's Creek Canal (Graph 10):

- Channel widths were measured at 12 locations in the lower tidal segment of the BCSA: seven were located along the main channel of Berry's Creek and five were located along the Canal. All the channel width measurements, except for location A along the main

channel and location I along the Canal, exhibit little variation over the 72-year period of analysis and are indicative of a stable stream.

- Channel width measurements at location A on the main channel of Berry's Creek are indicative of the development activities in the general vicinity of the confluence of Berry's Creek and the Canal. Prior to the period of analysis, a rail crossing built across Berry's Creek between 1902 and 1908 significantly constricted the natural channel just downstream of cross section location A. Subsequently, Route 3 was constructed between 1930 and 1947 resulting in a 94 foot reduction in the channel width, and in the period between 1968 and 1971 the Rutherford landfill road was constructed resulting in an 86 foot reduction in the channel width of Berry's Creek at this location. Consequently, this area of the Berry's Creek channel has been reduced from a width of 183 feet in 1930 to a width of 52 feet in 2002 as a result of human activities in the area and as a consequence of channel constriction prior to the period of analysis.
- Between 1951 and 1961, the channel width at locations B through F decreased somewhat, but then increased again between 1961 and 1968. The cause of this variation is not apparent, but the channel regains its stability in subsequent analysis years.
- Based on the average width at each measurement location along the main channel (locations B through G), excluding location A, the average channel width of Berry's Creek varies between 149 (location B) and 191 feet (location C). The average channel width below the confluence of Berry's Creek and Fish Creek (i.e., location G) is not substantively different than those cross sections upstream of the confluence.
- Channel widths in Berry's Creek Canal vary by less than 10% of the average channel width for any year, with the exception of location I. Channel width measurements at location I along the Canal reflect an increase of 142 feet in the width between 1951 (192 feet wide) and 1971 (334 feet wide), after which time the channel width measurements are stable. Based on a review of the aerial photographs during this 20-year period (i.e., aerials of 1951, 1961, 1968, and 1971) the increased width is a result of human activities (as channel meandering/sinuosity is not evident) possibly associated with dredging to increase the tidal prism to dilute the sewage effluent from the Triboro (Rutherford) POTW.

Similar to the other tidal segments, the overall observation and conclusion for the lower tidal segment of the BCSA is that the channel widths remained stable during the period of evaluation and only varied in response to human modifications/influences in the watershed.

Summary

Based on a quantitative assessment of the channel widths at numerous locations throughout the BCSA, there has been little change in the main channel of Berry's Creek or the Canal over the 72-year period between 1930 and 2002. The most substantial variations in channel stability have been caused by human activities and are associated with development, filling, dredging, and/or road crossings. Other minor variations that don't affect the overall pattern of stream width may be attributed either to natural changes or, more likely, to measurement errors related to the quality, accuracy, and/or scale of the aerial photographs.

3.2.3. Tributary Geometry

In order to further assess channel stability in the BCSA, the following naturally formed tributaries shown on the 1896 map were selected for analysis in the upper, middle, and lower tidal segments of the BCSA, respectively: an unnamed tributary in Eight-Day Swamp, Ackerman's Creek, and Fish Creek. Assessment of the selected tributaries involved measuring the stream length (i.e., centerline distance), belt width, and meander wave-length, as well as several points of channel width along each tributary (Rosgen, 1996). These metrics of channel dimensions were specifically selected due to their sensitivity to environmental stresses. The measurement locations for each tributary are shown in detail on the insets provided on Figures 5A/B through 7A/B, and the results of the channel measurements are graphically represented on the figures as graphs.

Eight Day Swamp (Upper Tidal Segment)

Based on the measurements obtained at fixed points for each of the selected years of analysis (refer to the inset and Graphs 3 through 5 presented on Figures 5A/B), the following observations were made for the unnamed tributary in Eight-Day Swamp located in the upper tidal segment of the BCSA.

- Channel widths were measured at 5 locations along the unnamed tributary for each year of analysis (Graph 3). Overall, the channel measurements of the tributary reflect an increase in width at all the locations over the 72-year period of analysis. Deviations from this pattern during specific periods of analysis (i.e., 1930 to 1947 at location *e*; 1951 to 1961 and 1961 to 1968 at location *f*; and 1971 to 1974 at location *g*) may be attributed to the quality/accuracy and scale of the aerial photographs when measuring such a narrow (i.e., < 45 feet wide) channel. Additionally, a decrease in width was observed at most locations between 1974 and 1989, although no cause (i.e. development) is readily apparent in the aerial photographs.
- The channel length measurements of the unnamed tributary indicate little variability over the 72-year period (Graph 4). In 1930 the stream measured 1,825 feet long and in 2002 the measured length was 1,812 feet – a difference of only 13 feet and a 0.7% change based on the overall average length of the stream (1,845 feet) calculated by adding all the stream length measurements and dividing by 10. The stream's greatest length measurement was in 1961 (1,938 feet representing a 5% increase from the average length), and the largest difference in the measured stream length between consecutive years of analysis (1971 and 1974) was 137 feet. As presented in Section 3.2.4 below, a total of 4 hurricanes occurred between 1951 and 1961 and another major storm occurred between 1971 and 1974. The occurrence of these storms may have affected the channel lengths during these periods. However, the differences in length may also be attributed to measurement variations associated with the variable quality/resolution of the aerial photographs for these three years.
- The belt width measurements of the unnamed tributary vary little over the 72-year period of analysis, and are indicative of a stable stream (Graph 5). The average length of the belt width is 194 feet and was calculated by adding all the belt width measurements and dividing by 10. The greatest difference of measurement (10 feet) between consecutive years of analysis occurs between 1989 (193 feet) and 1994 (203 feet), and represents a 5-year period. The remaining years' measurements are fairly consistent and range between +11 and -16 from the average width measurement. These differences in measurements are inconsequential when considering the scale, accuracy, and quality of the aerial photographs.

- Similar to the belt widths, the meander wave-length measurements of the unnamed tributary exhibit little variation over the 72-year period of analysis, and are indicative of a stable stream (Graph 5). The average meander wave-length is 208 feet and was calculated by adding all the meander wave-length measurements and dividing by 10. Measurements obtained between 1947 and 2002 only deviated from the average length by +/- 7 feet: the 1930 measurement (194 feet) was 13 feet less than the average length.

The overall observation and conclusion is that the unnamed tributary in Eight-Day Swamp located in the upper tidal segment of the BCSA was largely unchanged during the period of analysis.

Ackerman's Creek (Middle Tidal Segment)

Ackerman's Creek was present in 1896 (Figure 2) and continued to function as a natural tributary of Berry's Creek in the middle tidal segment until the period between 1961 and 1968. At that time, the original channel was filled and the name was transferred to a linear ditch located just north of the original channel. The assessment of Ackerman's Creek focuses on the original channel only; therefore, the period of analysis is limited to the 31-year period between 1930 and 1961. Based on the measurements obtained at fixed points on the 1930, 1947, 1951 and 1961 aerial photographs (refer to the inset and Graphs 7 through 9 presented on Figures 6A/B), the following observations can be made for Ackerman's Creek.

- The channel widths of Ackerman's Creek were measured at 6 locations for the period between the years 1930 and 1961 and are indicative of a stable stream (Graph 7). The greatest period of change for all but one of the locations (i.e., location f) occurred between 1951 and 1961, and may be attributed to the severe storm events experienced during this period and/or the lower quality/resolution of the 1961 aerial, especially when measuring such a narrow (i.e., < 55 feet wide) channel. Similarly, the quality of the 1930 aerial photograph (i.e., dark image with blurred lines) likely contributed to the difference in channel width at location f between 1930 and 1947, after which period the channel width remains nearly constant at this location.
- The channel length measurements of Ackerman's Creek indicate little variability over the 31-year period prior to its filling between 1961 and 1968 (Graph 8). The stream length exhibited little difference between 1930 and 1951 (i.e., 4,161 feet and 4,288 feet). The

stream's greatest length measurement (4,454 feet) was in 1961, and the greatest increase between consecutive years of analysis (1951 and 1961) was 166 feet and reflects a 4% change based on the overall average length of the stream (4,293 feet) calculated by adding all the stream length measurements and dividing by 4. As previously mentioned, the occurrence of 4 hurricanes between 1951 and 1961 may have affected the tributary's channel length during this period. However, these minor variations may also be attributed to the lower quality/resolution and accuracy of the 1961 aerial photograph.

- The belt width measurements of Ackerman's Creek remained constant over the 31-year period of analysis between 1930 and 1961, except for an approximate 8 foot difference measured between the years 1930 and 1947 (Graph 9). The belt width measurements for years 1947, 1951, and 1961 were all 493 feet, and the 1930 measurement was 485 feet. The belt width measurements remained constant/stable even though this period included several major storm events.
- Similar to the belt width analysis, the meander wave-length measurements of Ackerman's Creek remained constant over the 31-year period of analysis between 1930 and 1961, except for a 10 foot difference measured between the years 1930 and 1947 (Graph 9). The meander wave-length measurements for years 1947, 1951, and 1961 were all 298 feet, and the 1930 measurement was 288 feet. Even though this period included several major storm events, the meander wave-length measurements remained stable.

The overall observation and conclusion is that Ackerman's Creek remained largely unchanged during the period of evaluation, except when directly altered by human activity.

Fish Creek (Lower Tidal Segment)

Based on the measurements obtained at fixed points for each of the selected years of analysis (refer to the inset and Graphs 12 through 14 presented on Figures 7A/B), the following observations can be made for Fish Creek located in the lower tidal segment of the BCSA.

- The channel widths of Fish Creek were measured at 6 locations for each year of analysis (Graph 12). Although there appears to be some variability in channel widths at each location over the years, this is likely attributed to observed modifications to the stream (i.e., construction of a road crossing) and the quality/accuracy of the aerial photographs

when measuring such a narrow (i.e., < 60 feet wide) channel. Specifically, locations *h* and *i* are located upstream and downstream of a road crossing that was constructed between 1961 and 1968. Prior to this period (i.e., between 1947 and 1961) the channel widths at these locations were stable, and following installation of the road (1968 to 2002) the measurements at these locations exhibited much more variation. In addition, some variability in channel width is observed at location *g* between 1974 and 2002, which could possibly be due to upstream propagation of changes created by the road crossing between locations *h* and *i*. All the measurements obtained in 1930 are greater in width than the 1947 aeriels and are not consistent with the relatively stable natural channel width pattern observed at measurement locations *d*, *e*, *f* and *g* – this could be attributed to the quality of the 1930 aerial photograph (i.e., dark image with blurred lines) which makes it difficult to discern the channel banks of Fish Creek. The unexpected channel width pattern could also be the result of storm impacts from the 2 hurricanes that occurred between 1930 and 1947 (Table 2).

- The channel length measurements of Fish Creek show a stable stream over the 72-year period (Graph 13). In 1930 the stream measured 4,762 feet long and in 2002 the measured length was 4,756 feet: a difference of only 6 feet and a 0.1% change based on the overall average length of the stream (4,789 feet). The stream's greatest length measurement was in 1994 (4,918 feet), and the largest difference in the measured stream length between consecutive years of analysis (1989 and 1994) was 146 feet or 3% of the overall average length of the channel.
- The belt width measurements of Fish Creek vary slightly over the 72-year period of analysis, but are indicative of a stable stream (Graph 14). The average length of the belt width is 600 feet, and the greatest difference between consecutive years of analysis (41 feet) occurs between 1930 (624 feet) and 1947 (583 feet) which represents a 7% change in length when compared to the overall average. The remaining years' measurements are fairly consistent and range between +10 and -9 from the average width measurement. These estimated differences in measurements are inconsequential when considering the scale, accuracy, and quality of the aerial photographs.
- The meander wave-length measurements of Fish Creek exhibited little variation over the 72-year period of analysis and are indicative of a stable stream (Graph 14). The average

meander wave-length is 468 feet and the range of deviation from this length for all the years of analysis was +7 to -9 feet. The greatest difference in measurement between two consecutive years of analysis (1930 and 1947) was 16 feet, a 3% change based on the overall average meander wave-length.

The overall observation and conclusion is that Fish Creek remained largely unchanged during the period of evaluation, except when directly impacted by human activity.

Summary

Based on a quantitative assessment of the geometry of three natural tributaries located in the BCSA, there has been little change in the geomorphology of the tributaries over the 72-year period between 1930 and 2002. Specifically, the channel length, belt width, and meander wave-length measurement of all three tributaries indicate stable streams. In addition, the most substantial variations in channel widths of the tributaries have been influenced by human activity and are associated with development/filling (i.e., the loss of Ackerman Creek between 1961 and 1968) and/or road crossings such as the Rutherford landfill road. Other minor variations that don't affect the overall pattern of channel stability and/or stream geomorphology are likely attributed to measurement variations related to the quality, accuracy, and/or scale of the aerial photographs.

3.2.4. Storm Impacts

Storms have the potential to affect the BCSA and alter the geomorphology of its waterways. Specifically, heavy precipitation results in increased movement of water and suspended sediment into downstream channels, and major storm events such as Nor'easters and hurricanes cause an increase in the tidal surge. When combined, these two events amplify the water elevation, volume, and velocity resulting in flooding, increased erosion, and sediment transport. Therefore, another means of assessing channel stability in the BCSA is to evaluate changes in geomorphology in response to major storm events that occurred over the period of analysis.

The aerial photographs were selected to bracket significant storm events (Table 2) such as a major nor'easter in 1950 and Tropical Storm Agnes in 1972. Also, a total of 4 hurricanes (Hurricane Carol in 1954, Hurricanes Connie & Diane in 1955, and Hurricane Donna in 1960) were recorded in the 10-year period between 1951 and 1961. A series of 4 hurricanes between

1996 and 1999, and repeated coastal and urban flooding between 1994 and 2002 were also evaluated. A “before and after” storm event analysis of the BCSA was conducted using the 1947-1951, 1951-1961, 1971-1974, and 1994-2002 aerials to identify any changes in channel stability that could influence the distribution of sediments in the BCSA.

- Comparison of the 1947 and 1951 aerial photographs did not reveal any noticeable changes in the physical template of the main channel and tributaries (Figures 5A/B, 6A/B, and 7A/B) or the surrounding wetland/open water areas (Figure 1) that could be attributed to a major storm activity. The nor’easter occurred in 1950 when the BCSA still had a considerable amount of wetland/open water area (3,995 acres) and a large number of channels (Table 6) that would naturally dissipate the impacts of a large storm event.
- Comparison of the 1951 and 1961 aerial photographs did reveal some noticeable changes in the physical template of the main channel and tributaries (Figures 5A/B, 6A/B, and 7A/B) and the surrounding wetland areas (Figure 1). Specifically, there was a loss in both the acreage of wetland/open water areas and the number of channels. However, review of the aerial photographs did not indicate any major physical changes (i.e., change in channel configuration/alignment, loss of levees, abandonment of developed land, etc.) that could have resulted from the 4 hurricanes that passed through the BCSA during this period. Hurricane Donna occurred in 1960, only one year prior to the selected year of analysis (1961); however, it is not possible to identify if a change occurred prior to the 1960 storm or after the storm because of the 10-year period between 1951 and 1961.
- Comparison of the 1971 and 1974 aerial photographs did not identify any physical changes to the watershed that could be attributed to the 1972 storm event (Figures 5A/B, 6A/B, and 7A/B). There were only a few minor changes (i.e., gain of approximately 2,015 linear feet of man-made channels and construction of the Peach Island Creek and Rutherford tide gates) that occurred during this 3-year period and these are associated with development in the area. In addition, Tropical Storm Agnes occurred in 1972 and a minimum period of 15 months elapsed between the time of the storm and the time when the 1974 aerial photograph was taken; therefore, it is difficult to determine if a change resulted from the storm or some other man-made influence/alteration.

- Comparison of the 1994 and 2002 aerial photographs indicated only 1 significant change in the channel morphology of the upper tidal segment of Berry's Creek that could potentially be attributable to the series of storms that occurred during this time period. Changes included the loss of a small island and a considerable amount of a channel bend; the merging/confluence of an old oxbow with the new channel alignment and the creation of an island; and, the widening of the main channel throughout this area. Hurricanes Bertha, Edouard, Irene, and Floyd all affected this region (Table 2) and may have been responsible for the observed changes in Berry's Creek, either individually or collectively. Furthermore, coastal and urban flooding was reported in this region annually, and in some cases more than once per year, during each year of this time period with the exception of 1997. It is possible that the repeated inundation and tidal surges associated with these storm events resulted in the alterations observed in this portion of the BCSA. However, no other substantial changes were observed in other segments of Berry's Creek or any of its tributaries during this time period.

In general, the Berry's Creek system is stable and was not significantly affected by the storm events evaluated in this analysis. This stability may have been inadvertently increased as the filling of wetlands has reduced the tidal prism of the BCSA, resulting in lower stream power in the waterways, with the corresponding reduction in stream discharge (Leopold et al, 1995; Richards, 2004). Detailed assessment of this factor will be evaluated as part of the water budget analysis.

A possible exception is the channel alterations observed in the Upper Tidal Segment between 1994 and 2002, during a time period of repeated severe storms and flooding in the region. The other storms events evaluated do not appear to have resulted in a long-term impact on the physical template of the BCSA watershed or the channel stability of Berry's Creek and its associated tributaries/channels. The level of resolution of this analysis may be enhanced by the review other sources of information/records that provide descriptions and/or photographs of the severity of the storm events in the BCSA, and acquisition of aerial photographs as close as possible to the dates of specific storm(s), but this additional level of analysis is not recommended at the present time.

4.0 SUMMARY OF FINDINGS

Based on the aerial photographs analysis, the 7,690 acre BCSA watershed has experienced substantial and repeated physical stresses during the last 100 years. These physical stresses include:

- A 63% reduction in the acreage of wetlands present since 1896;
- An overall loss of 17.5 miles (92,526 linear feet) of tidal tributaries, despite certain increases related to construction of drainage ditches for mosquito control;
- Addition of tide gates to regulate flow and reduce the tidal flux;
- Elimination of naturally sinuous channels and their replacement with straight ditches in freshwater (Riser Ditches) and brackish portions of the watershed;
- Nearly complete urbanization of the watershed (80% developed versus 20% wetland);
- Addition of 42 waterway crossings with corresponding constrictions of flow; and
- At least 18 major storm events with amplified storm tides, including nor'easters and hurricanes.

The cumulative result of these changes is:

- A substantial reduction in the tidal prism and stream discharge, and corresponding stream power (Leopold et al, 1995; Richards, 2004), especially storm tides, due to filling of wetlands;
- A substantial increase in the volume of runoff from upland areas as the percentage of impervious surfaces increased with development;
- A substantial reduction in the tidal prism due to the placement of tide gates (approximately 4 tide gates) along tributaries;
- Shifting of the head of tide to locations downstream due to the tide damping effect of tide gates;
- Shifting of the salinity profile of the waterways due to changed (reduced) tidal volumes and the reduction of storm tides in moving tributaries; and

- Changes in the sediment transport dynamics from upland areas, as well as sediment movement from the Hackensack River.

Taking these changes into account, a relevant hypothesis is that the morphology and movement of the stream channels should reflect these stresses through measurable changes over the course of the period of analysis. In addition, these changes should be clearly evident as there are continuing changes in tidal stream geomorphology as sea level rises - approximately six to eight inches over the period of the aerial record (Stanley et al., 2004).

Three lines of evidence evaluated to test the above hypotheses are summarized below:

- Stream channel width is a parameter that reflects peak stream discharge and bank stability. If tidal or storm flows increase and the banks are not stable, the stream width will typically widen through bank erosion.
 - Stream channel widths exhibited no increasing trends anywhere in the BCSA.
 - Constructed channels parallel to Berry's Creek and Berry's Creek Canal and within 50 feet of the main channel remained stable once constructed, unless physically altered by human activity.
 - Locations adjacent to flow constrictions, caused by filling of wetlands and/or stream channels, remained stable following the filling.
- Stream channel morphometrics such as sinuosity, meander wavelength, and belt width, as well as overall channel configuration, are sensitive to hydraulic and other physical stressors.
 - Natural channels – analysis of a well-developed and naturally formed channel in each of the BCSA tidal segments along Berry's Creek found no changes that indicate changes in morphology or stability. The overall channel patterns and location were highly stable over the study period.
 - Created channels – created channels/ditches of varying size are abundant throughout the BCSA (tidal and non-tidal areas). In nature, straight channels rarely occur in low-gradient areas such as the BCSA, and constructed straight channels become sinuous over time. In the BCSA, the constructed straight channels have remained stable with limited maintenance for the past few decades, if not longer.

The factors that account for this stability will be assessed as part of the hydrodynamic studies, and likely include the following:

- All of the channels are low gradient;
 - Bank deposits have high silt and clay content, which adds to sediment cohesion;
 - Upland flows are small compared to the tidal flux; and
 - *Phragmites* dominates the vegetation and stabilizes the banks with its dense and intricate pattern of roots and rhizomes.
- Horizontal channel movement is natural but very slow in a stable system (Rosgen, 1996; Rosgen, 2006 and references therein). Although the aeriels are not adequately georeferenced to provide for detailed high resolution analysis, the horizontal distribution of the primary and secondary channels were compared side-by-side over the study period. The result was that no trends in horizontal movement were evident.

These lines of evidence, combined with the geophysical analysis of sediments in the major waterways of the BCSA (Earthworks Inc., 2008) and radioisotope dating of sediment areas indicating steady accrual of sediment in the BCSA (Weis, et al., 2005; Goeller, 1989), support a conclusion that the BCSA waterways and wetlands are a highly stable landscape that is resistant to a large range of natural and human stresses. This finding is also consistent with the decreasing tidal prism due to infill of wetlands, leading to less erosive stream channels as a result of decreased stream power.

The interrelationship of these findings and other BCSA studies will be investigated throughout the Detailed Remedial Investigation/Feasibility Study.

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FIGURES

**UPDATED AERIAL PHOTOGRAPH ANALYSIS
TECHNICAL MEMORANDUM
for
BERRY'S CREEK STUDY AREA:
SCOPING ACTIVITIES TASK 2**

